THE SPECTRUM AND SPECTRUM SCALES.

By J. T. LOVEWELL, Topeka, Kan.

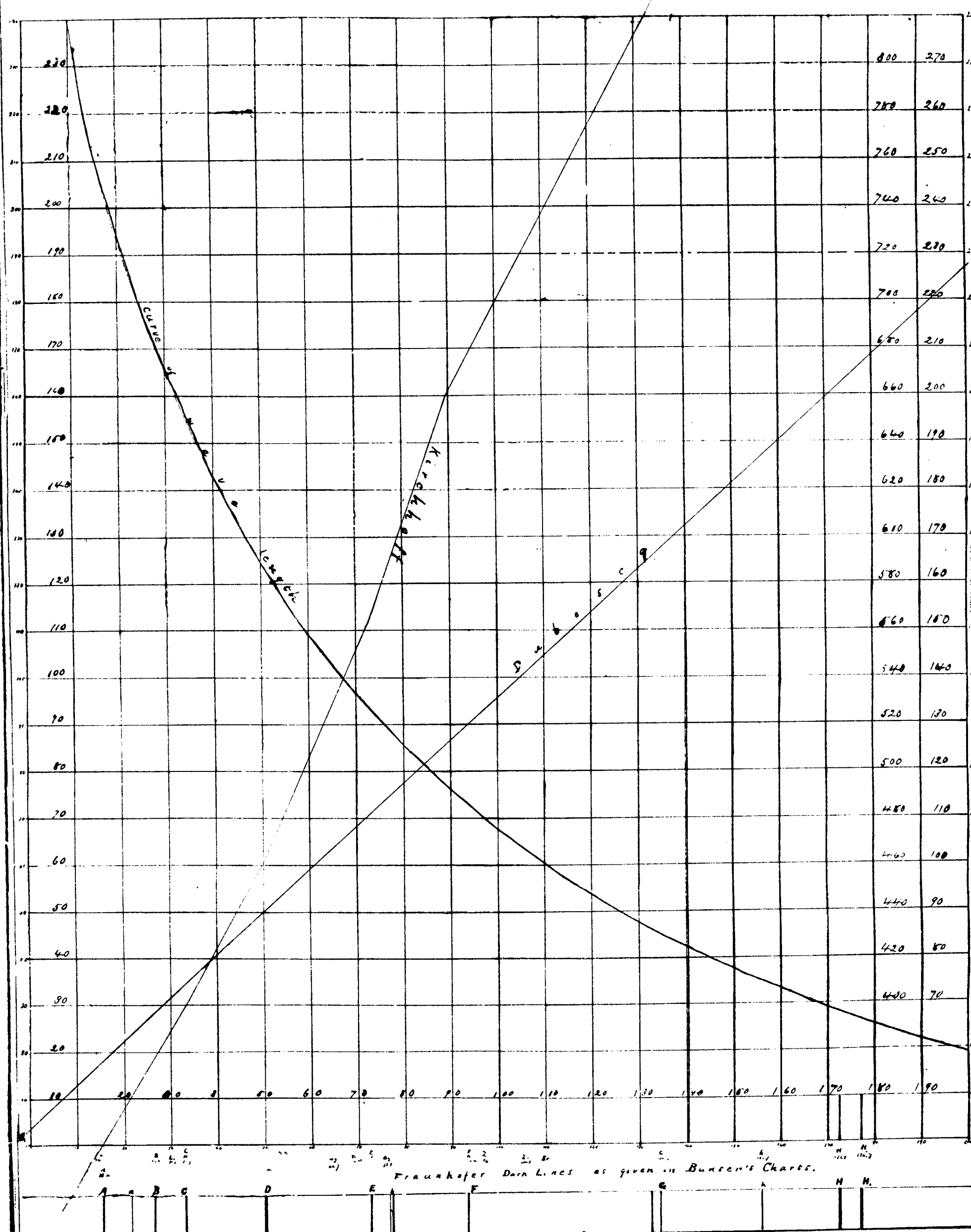
IN the ordinary laboratory spectroscope we may often observe a line which we wish to compare, for identification, with numbers in the tables of Kirchhoff, or with wave-lengths as given in Angstrom's and similar charts. Perfect agreement of readings cannot be expected in different refraction spectroscopes, where lines are designated either by the angle of deviation or by the number of a photographed scale, which is brought into the field of view with the spectrum. Every prism has its own problem of refraction, and every photographed scale must have imperfections. In the diagram herewith presented use is made of curves, which are now employed in the discussion of so many physical problems. The spectroscope with which observations were made was a Duboscq single-prism instrument, with the ordinary photographed scale reflected into the field of the observing telescope. The scale numbers were from 1 to 200, and the first problem was to compare these with the numbers of Bunsen's charts of flame spectra. On a sheet of cross-section paper, ruled in inches and tenths, the lower margin was marked with the Bunsen chart numbers, which were to be the abscissas of the proposed curve. A few of the Fraunhofer lines of the solar spectrum are drawn in the margin as given in Bunsen's charts. For ordinates of the curve, readings of the spectroscope were used; for solar lines and for a great variety of flame spectral lines, obtained from soluble salts of metals, brought into the flame of a Bunsen lamp. The scale number of the observed line forms the ordinate of the curve, and these numbers are placed on the left-hand margin of the chart. The scale was adjusted so that the number 50 coincided with the sodium line or the Fraunhofer D line of the solar spectrum. The abscissas and ordinates of a large number of points in all parts of the spectrum were next found, and through the mean position of these points a curve was drawn which proved to be practically a straight line. Had the spectroscope employed by Bunsen been exactly like the one used here this line would have been at an angle of 45 degrees, but it was found to have an angle less than that, measured from the horizontal.

The Bunsen and Duboscq scales were supposed to be alike, as were also the prisms, but 50, the number to which they were adjusted, is the only point of exact coincidence where the lines cross.

When the Bunsen line of 160 is examined, the Duboscq number is 150. Drawn on the original scale the Duboscq curve is not quite a straight line, but has slight deviations, which are not noticeable when reduced to one-fourth the size, as in the diagram accompanying this paper. By the aid of this curve any observed line may at once be compared with the Bunsen charts. In a like manner a curve from Kirchhoff's scale numbers is prepared, only in this case the spectrum lines were obtained from the electric spark. It was by this means that Kirchhoff obtained most of his numbers. His spectroscope contained four prisms of flint glass, three of which had a reflecting angle of 45 degrees and the fourth an angle of 60 degrees. These were mounted on metallic stands with leveling screws, and suitably placed on a circular iron plate, upon the rim of which the telescopes were clamped. The light for the metallic spectra was obtained by three or four Bunsen elements acting on a large Ruhmkorff induction coil. A heliostat directed the solar rays upon the object-glass of his collimator, and his first care was to represent the lines of the solar spectrum as faithfully as possible, as they appeared in his spectroscope. The distance apart of the lines was measured by movement of an arm which was attached to the observing telescope, and this movement was estimated by the divided circle, with a micrometer screw attached. Record was made of the lines on a chart by means of a kind of equal-part machine, and the intensity and breadth of the lines were shown, the former by three shades of ink. Above the spectrum as thus exhibited he placed a millimeter scale, with a starting-point selected at pleasure. He chose such a position as brought the D line very near the 100 mark on the scale. After the solar spectrum was thus recorded, Kirchhoff proceeded to find the places of the metallic spectral lines as compared with the dark solar lines. To accomplish this he observed simultaneous spectra of the sun and of the metals. The solar beam was received into the upper half of the slit, and the metallic rays into the lower half, first falling on a glass prism so placed over the lower part of the slit that the ray, after a twofold total reflection, fell into the field desired.

The results of these observations were recorded with the same care as the former, and both were repeated until satisfactory agreement was obtained. Kirchhoff observed that a great difference resulted in the appearance of the lines as the temperature changed and as other vapors were present. Angstrom denies that there is any real change in the position of the lines, and takes issue with Plucker on this point. Kirchhoff's observations extended from

CURVES OF WAVE LENGTH



the line D to somewhat beyond the line F, and his pupil and assistant, Hofmann, with the same apparatus and by the same methods, observed and mapped the rest of the spectrum from a little below A to a little beyond G. From the result of their labors we have what are commonly referred to as Kirchhoff numbers. Thalen with different instruments subsequently extended this scale to H. The Kirchhoff scale numbers are given in the right-hand margin of the diagram, and with these as ordinates, and the same abscissas before used, the Kirchhoff curve is drawn; and by comparing its ordinates with those having the same abscissa on the Duboscq curve, the identity of any metallic line seen by the Duboscq instrument may be established. The most exact designation of spectrum lines is doubtless by wave-lengths. The Swedish physicist, Angstrom, reduced the Kirchhoff numbers to wave-lengths, as well as greatly extended his observations, and the numbers taken from his charts are the abscissas in the wave-length curve here shown. The unit is one divided by 10 seventh power, expressed in millimeters, decimally 0.00000001 mm. It will be seen that the curve is tolerably regular and convex from the axis of abscissas. The wave-lengths are given in the right-hand margin, from 400 to 800 in units, as above indicated. We may thus find in any observation in this single-prism spectroscope the corresponding Bunsen chart numbers, the Kirchhoff numbers, or the wave-lengths.

Wollaston, in 1802, appears to have been the first to observe the dark lines in the solar spectrum which are always produced if the light falling on the refracting prism issues from a narrow slit parallel to the axis of the prism instead of a circular aperture, as in Newton's experiments. These lines were not carefully studied till 1814, when Fraunhofer, a celebrated Munich optician, took up the subject and carefully studied these lines. He designated seven different lines or groups of lines by the first seven letters of the alphabet, which continue to be the common names of these lines. He counted in the spectrum, obtained by his instruments, 574 lines. He devised a grating, made by winding fine platinum wire on the threads of two parallel screws, soldering the wire to them, and then cutting the wire away on one side. Letting his narrow beam of solar light fall on this grating, and making use of the principle of interference developed by Young, Arago, and Fresnel, he was able to measure the wave-lengths of many of these dark lines. It was not, however, till 1860 that Kirchhoff, by a splendid induction, explained the cause of these dark lines and demonstrated that the

spectroscope not only showed the constitution of earthly bodies, but could analyze the sun and stars.

No limit has been found in the number of solar lines, nor are they confined to the visible spectrum. Photography comes to our aid in studying the invisible spectrum, especially of the violet end. Wonderful improvements have also been made in the manner of obtaining the spectrum. In place of the grating of fine wires devised by Fraunhofer rulings are made on speculum metal with as many as 20,000 lines to the inch, by which the spectrum is spread out to twelve feet or more. These photographic charts far surpass the best results of Kirchhoff and Angstrom. In the chemical laboratory, however, the refraction spectroscope must remain the common instrument, and the method of curves herewith presented will be found a useful adjunct to its use.